SECTION 6

POLLUTANT UPTAKE DISCUSSION

Review of research literature offers insight into the process of lead, zinc, and TPH accumulation in wetland emergents. In this section, the abilities of the pollutant uptake study species to accumulate lead, zinc, and TPH are compared to each other and to past research on the same or similar species.

BIOACCUMULATION

Evidence of bioaccumulation by a wetland plant species may be indicated by the retention of pollutant levels in plant tissues above substrate pollutant levels. Bioaccumulation may also be indicated by increasing levels of pollutants in plant tissues over time, regardless of substrate pollutant levels. *Iris pseudacorus* was the only one of the five study species to retain pollutant levels (TPH only) above the substrate pollutant levels. However, all five species retained levels of all three pollutants greater than the same species from the control sites. This seems to indicate a capacity by these five species to respond to higher substrate levels of pollutants with higher levels of pollutants in their tissues.

Over time, pollutant levels in the study species varied depending on the species, tissue, and specific pollutant. Several factors may be influencing matrix concentrations of pollutants.

TPH

Two factors may be altering matrix concentrations of TPH. These factors are as follows:

Metabolization of TPH by the Plant. Seidel (1976) found that *Scirpus lacustris* can store and use phenol (a common aromatic found in petroleum products) in its stems for amino acid production when cultured in phenol solution concentrations of 10 to 100 mg/l and when a phenol solution was injected into the rhizome. Lytle and Lytle (1987) found that the coastal rush, *Juncus roemerianus*, could retain petroleum hydrocarbon concentrations of 9,000 ppm in the shoot tissues. They also reported evidence that naphthalene and other aromatic petroleum hydrocarbons were being translocated to the shoot tissues and metabolized. If the shoot tissues of any of the pond study species had the capability to metabolize

TPH or any of its fractions, then measurements of shoot TPH levels would reflect only a partial measure of pollutant removal performance, hence the persistently low levels of shoot TPH levels found during the study.

Presence of Petroleum-Oxidizing Microbes. The other factor that may be influencing matrix TPH levels is the presence of petroleum-oxidizing microbes associated with the rhizosphere (root zone) of emergent wetland plants. Morozov and Torpishcheva (1973) found that *Scirpus lacustris*, *Typha latifolia*, and *Typha angustifolia* supported a diversity of microorganisms that oxidized petroleum products with greater efficiency than microorganisms from soils without vegetative growth. This may be due to the creation of an oxidized soil zone associated with radial oxygen loss from the plant rhizosphere. Michaud and Richardson (1989) reported that *Typha latifolia*, *Sparganium americanus*, *Juncus effusus*, *Scirpus cyperinus*, and *Eleocharis quadrangulata* all displayed various levels of radial oxygen loss in their rhizospheres. *Typha latifolia* showed the greatest radial oxygen loss, followed by *Juncus effusus*. Merezhko (1973) indicated that the relationship between petroleum-oxidizing microbes and soil-oxidizing emergents may be reciprocal, with the microbes providing nutrients from the digestion of petroleum hydrocarbons.

Variations in soil TPH levels may be due to the action of soil microbes and the individual ability of each emergent species to provide them with oxygen. The significantly low levels of TPH in soils associated with *Iris pseudacorus* may be partially due to this effect. The combined action of pollutant uptake and degradation of emergents and the soil microbes they support may account for the significant reduction in soil TPH levels over the study. The mean of all soil TPH levels at the pond for each sampling event reduced by half from July 1991 to September 1991, and half again in October 1991 (Figure 6-1)

The chemical profiles of petroleum byproducts include a wide variety of long- and short-chain hydrocarbons, as well as cyclic aromatic compounds that have widely differing physical properties; these variations may also account for the discrepancies in matrix TPH levels. Petroleum-oxidizing microbes and emergent macrophytes prefer shorter-chain hydrocarbons and single- to double-ring aromatics for metabolization. Larger and more complex compounds, therefore, must undergo physical degradation such as photochemical oxidation or weathering in order to be made available for microbe or macrophyte utilization (Portier and Palmer 1989). The rate of sedimentation of TPH may exceed the rate of physical degradation and subsequent microbe/macrophyte metabolization, leading to soil TPH levels greater than those in the plant tissues.

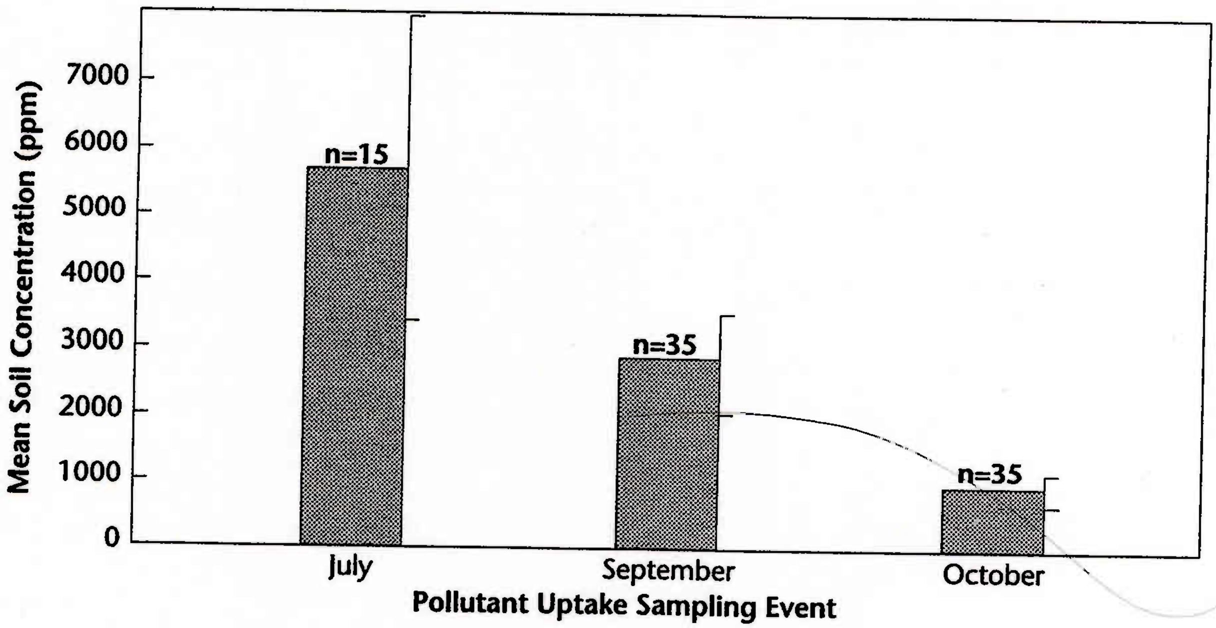


Figure 6-1. Mean Soil TPH Concentrations of all Samples for Each Sampling Event

Lead and Zinc

Kulzer (1990) reported that aquatic macrophytes differ in their ability to assimilate and store heavy metals such as lead and zinc in their tissues. Statistical comparison of the pond study species supported this observation, as the species differed significantly in their tissue lead and zinc concentrations. Matrix levels of lead and zinc, however, were uniformly low, with no significant evidence of bioaccumulation by plant tissues above soil lead and zinc levels. *Sparganium sp.* and *Eleocharis ovata* were notable exceptions, with root and soil levels for both lead and zinc statistically equal, displaying some level of bioaccumulation, at least in the root tissues, even though root and soil concentrations were generally low.

Several factors may be influencing the availability and absorption of lead and zinc, resulting in overall low plant tissue and soil concentrations. Plants can only absorb metals in their ionic phase. Estimates from a literature review by Kulzer (1989) indicate that 95 percent of lead and 25 percent of zinc carried by stormwater runoff exists in the particulate phase. After initial sedimentation of the particulate phase in the pond, wetland soil and water chemistry favors the precipitation of the ionic phase of lead and zinc through chelation (Shaheen 1982). This combination of factors may contribute to dissolved lead and zinc concentrations too low to be absorbed into plant tissues.

Microorganisms associated with the plant rhizospheres not only metabolize petroleum hydrocarbons but also detoxify toxic metals such as lead and zinc by binding them to ligands, forming nearly insoluble sulfide bonds (Portier and Palmer 1989). Radial oxygen loss from the plant roots and rhizomes fosters conditions that encourage healthy populations of these chelating microorganisms (Michaud and Richardson 1989). The action of these microorganisms results in retention of lead and zinc in the soils, intercepting these metals before reaching plant tissues. Plant-associated soils from the pond study corroborate the microbial metal removal hypothesis, with lead and zinc concentrations significantly greater than shoot lead and zinc levels in all cases except zinc in *Sparganium sp.* Soil lead and zinc levels were appreciably greater than root levels for *Typha latifolia, Scirpus acutus* and *Iris pseudacorus*, of which *Typha latifolia* and *Iris pseudacorus* have considerable root masses with greater surface area for radial oxygen loss and subsequent microbial chelation.

Plants themselves also produce compounds that chelate toxic metals that enter their tissues. Called phytochelatins, these compounds neutralize metals by forming insoluble sulfide bonds. Grill et al. (1985) isolated these phytochelatins and found that they closely resemble the chelating agents found in other organisms. Because the roots/rhizomes of most vascular plants function as the main nutrient absorption organ, it might be expected that toxic levels of lead or zinc would be bound by phytochelatins in the root tissues before they could interfere with plant photosynthesis in the shoots. T-test comparisons of root and shoot lead and zinc levels broadly support the likelihood of this process, with root lead and zinc levels significantly higher than shoot levels ($p<0.05$ or $p<0.01$). However, *Iris pseudacorus* shoot and root tissues did not differ markedly for zinc.

Zinc and lead, while both toxic heavy metals, affect plant tissues variably according to each species' tolerance levels. In low concentrations, zinc acts as an important micronutrient in plant systems. Therefore, depending on species, a portion of zinc uptake in plant tissues represents both physiological demands and, possibly, nutrient storage. Excess levels of zinc in plant tissues above those needs would then be in a fixed, detoxified state. Equal concentrations of zinc in the root and shoot tissues of *Iris pseudacorus* may reflect a stronger demand for zinc as a micronutrient in this species. In contrast, lead serves no nutritional function, entering plant tissues by being "mistaken" for a similarly charged micronutrient. The action of phytochelatins, lack of nutritional demand, higher adsorption of lead by sediments in comparison to zinc, and the relatively low solubility of lead in solution, especially in wetland conditions, results in overall low levels of lead in plant tissues. Mean root and shoot levels of lead over the sampling period confirm this presupposition, with persistently low lead concentrations, especially in the shoots, where levels were very close to the detection limit of 1 ppm.

MACROPHYTE PERFORMANCE

The overall suitability of each study species for pollutant removal in constructed wetland applications relies on the quantity and quality of pollutant removal provided by that species. At the most basic level, the pollutant uptake performance of a wetland plant species can be gauged by the quantity of a pollutant absorbed per unit weight of plant biomass per unit area of a species. Emergent wetland plants also provide pollutant removal beyond bioaccumulation in their tissues by reducing flow, trapping pollutant-laden sediments, and hosting pollutant-fixing/metabolizing microorganisms in their soils, although these processes were not directly investigated in this study. Therefore, the value of a wetland species as a pollutant mediator for constructed wetland applications depends on how it functions in each of these capacities.

Typha latifolia

Both the pond study pollutant uptake data and the research literature show that *Typha latifolia* is a powerful pollutant mediator. In the pond study, *Typha latifolia* accumulated concentrations of TPH, lead, and zinc per unit area 2 to 13.6 times higher than the other study species (after adjustment for biomass). The majority of the pollutants were concentrated in *Typha latifolia* root tissue, retaining elevated levels of TPH, lead, and zinc over all other study plant tissues, with 7.9, 0.042, and 0.314 g/m^2, respectively. *Typha* shoots stored only moderate levels of lead (0.007 g/m^2) but appreciable levels of zinc (0.153 g/m^2) and TPH (2.06 g/m^2).

Typha latifolia appears frequently in the research literature concerning pollutant absorption. Mudroch and Capobianco (1978) tracked the changes in lead and zinc levels in *Typha latifolia* root and shoot tissues over an April-through-September growing period. They found that *Typha latifolia* shoots ranged from approximately 10 to 1 ppm over the study period for lead and from 30 to 5 ppm for zinc, and that root tissues held from 60 to 15 ppm for lead and 60 to 25 ppm for zinc. The range in *Typha latifolia* shoot concentrations during the South Base pond study fell at the extremes of these ranges, with 40 to 25 ppm for zinc and 2 to 1 ppm for lead. *Typha latifolia* root zinc levels far exceeded the Mudroch and

Capobianco study, spanning from 235 to 53 ppm, while root levels of lead from 46 to 34 ppm fell within their reported range.

In a lead and zinc dosing experiment, Zhang et al. (1990) found that *Typha latifolia* responds to increasing environmental lead and zinc concentrations, with elevated tissue levels as high as 1,800 ppm for zinc in the rhizome and 976 ppm for lead in the rhizome. *Typha latifolia* tissues showed bioaccumulation of lead and zinc, but a lower steam tissue concentration than for root and rhizome. Such data suggest that *Typha latifolia* has a broad capacity to assimilate lead and zinc in its tissues, especially the root/rhizome, and that the differences in lead and zinc levels from study to study may be attributable to variable exposure levels, among other factors.

Studies regarding the absorption of petroleum hydrocarbon by *Typha latifolia* are scarce. Merezhko (1973) indicated *Typha latifolia* can tolerate oil concentrations of 1 g/L and that plants exposed to those levels had greener shoots, better turgor and increased shoot formation. The pond study shows that *Typha latifolia* is a significant accumulator of petroleum hydrocarbons, potentially capable of absorbing approximately 10 grams of oil per square meter or 100 liters of oil per hectare in the tissues alone.

Beyond tissue accumulation of TPH, lead, and zinc, *Typha latifolia* further facilitates pollution removal by growing rapidly and forming dense stands that reduce flow and hence increase sedimentation of suspended particulates that carry pollutants. *Typha latifolia* had the highest mean soil concentrations for TPH, lead, and zinc over the pond sampling period. When pollutant-laden sediments become trapped in the root zone, the oxidizing microbes that *Typha latifolia* supports in its rhizosphere metabolize petroleum hydrocarbons and chelate heavy metals such as lead and zinc.

Considered a nuisance species by many wetland ecologists, *Typha latifolia* can reduce the species diversity and richness of a wetland because of its aggressive exclusion of other emergent wetland species. However, in a managed setting that includes harvesting and thinning of *Typha latifolia* stands on a seasonal basis, both species diversity and the benefits of pollutant removal can be maintained.

Scirpus acutus

Of the species studied, *Scirpus acutus* had the third highest TPH removal capability. Per unit area of biomass, *Scirpus acutus* root tissues absorbed on average 2.26 g/m^2 of petroleum hydrocarbons. However, *Scirpus acutus* did not directly assimilate significant amounts of lead, TPH, or zinc in its root tissues.

The value of *Scirpus acutus* as a pollutant mediator may lie in sediment entrapment and root-associated microbial oxidation. Although there is a lack of research on the ability of *Scirpus acutus* to remove pollutants, Michaud and Richardson (1989) found that the related species, *Scirpus cyperinus*, harbored oxidizing microbes in its root zones. Morozov and Torpishcheva (1973) reported that *Scirpus lacustris* had the same capability. *Scirpus lacustris* was also the focus species in Seidel's now famous research concerning aromatic petroleum hydrocarbon uptake and utilization. Such pollutant removal traits may be common to the genus *Scirpus* and implicate *Scirpus acutus* as a potential pollutant mediator.

Iris pseudacorus

Iris pseudacorus root tissues stored the second highest amount of TPH of the pond species (4.01 g/m^2 per unit area). At 0.86 g/m^2, the plant's shoot tissue loading of TPH was the highest of all the species studied. However, *Iris pseudacorus* proved to be a relatively poor accumulator of lead and zinc, with the lowest total biomass loadings per unit area of all the study species. Because of its extensive rhizome, *Iris pseudacorus* may supply enough oxygen to its rhizosphere to support substantial populations of oxidizing microorganisms.

Sparganium sp. and *Eleocharis ovata*

Sparganium sp. and *Eleocharis ovata* displayed similar patterns of pollutant removal. For both the root and shoot tissues, *Sparganium sp.* and *Eleocharis ovata* had the highest and second highest mean root tissue concentrations of lead and zinc over the sampling period, with 68.9 and 44.8 ppm for lead, and 307.8 and 169.1 ppm for zinc. *Sparganium sp.* and *Eleocharis ovata* also held the first and second highest shoot tissue concentrations of lead and zinc, with 10.8 and 4.4 ppm for lead and 180.1 and 85.7 ppm for zinc. *Sparganium sp.* also held the second highest mean root TPH levels (1,938 ppm) and the highest mean shoot TPH levels (906 ppm) over the sampling period.

Unfortunately, neither *Sparganium sp.* nor *Eleocharis ovata* produce large enough biomass per unit area to constitute a major source of pollutant uptake. *Sparganium sp.* and *Eleocharis ovata* had the second and third highest loadings of lead and zinc for total biomass per unit area, respectively, but they were far surpassed by *Typha latifolia* loadings.

Conversely, both *Sparganium sp.* and *Eleocharis ovata* had the lowest loadings of TPH. Both species, however, have the potential to remove significant quantities of lead and zinc if grown in higher densities.

SECTION 7

VIGOR DATA ANALYSIS

This section discusses the responses of the six individual study species to variable levels of inundation, as represented by relative elevation. Responses to changes in season are also analyzed for significant trends, and the water depth tolerance range of the clump species, as represented by relative elevation, are reported.

DEFINITIONS

All linear measurements such as basal circumference, height, and relative elevation were taken in feet. Stem number represents the number of individual stems per plant. Inflorescence number indicates the number of stems per individual plant bearing inflorescences regardless of the stage of flower development. The relative elevation of a plant refers to the water level of the pond when the level just reaches the base of a plant. The water level itself is relative to a "zero" point proximal to the pond outflow. Negative water depths indicate areas of the pond lower than the established zero point. All relative elevations below the mean study water level of 1.59 feet are considered "flooded." Elevations above the mean pond water level are assumed to be constantly wet and intermittently inundated for short periods.

STATISTICAL METHODS

The strength of the relationships between each data set of individual vigor measurements and their corresponding relative elevational gradients was tested using regression analyses. The statistical significance of the relationships was tested using analysis of variance (ANOVA). Using the Durbin-Watson test, the assumption that there is no serial correlation of the error terms in the regression analysis was tested. All regressions showed no serial correlation except the May 1992 *Scirpus acutus* inflorescence regression, which had a positive correlation score. The assumption that the residuals have a mean of zero was met by all regressions.

R squared (R^2) values represent the percentage of the dependent variable (vigor measurements) that can be explained by the independent variable (relative elevation). R^2 values are reported in decimal notation; for example, 0.61 equals 61 percent. ANOVA significant F values report the level of confidence that the relationship between variables is significant, or, more precisely, that the slope of the regression line differs significantly from a slope of zero. An ANOVA significant F value of 0.001 means that the probability of a significant relationship between the variables is 99.9 percent confident (1.000 to 0.001). Significant F values were considered significant up to the 0.05 level of confidence.

INDIVIDUAL SPECIES

The relationship of changes in each growth parameter to variation in relative elevation was evaluated using regression analysis and ANOVA for each individual species at each sampling event. The study species that grow as discrete individual plants were the following: *Juncus ensifolius, Scirpus cyperinus, Scirpus acutus, Juncus effusus, Scirpus microcarpus*, and *Juncus tenuis*.

Juncus ensifolius

Height and basal circumference measurements for *Juncus ensifolius* were taken on every sampling event during the study. Basal diameter measurements were taken instead of circumference in December 1991. Inflorescences were counted on every sampling event except December 1991. Stems were not monitored because they were too numerous to be counted accurately. All measurements were measured along an elevation gradient spanning from 1.31 to 1.60 feet.

Regression analysis of basal circumference for August and October 1991 shows that elevation strongly determines the vigor measurement (R^2=0.77 and 0.61), with girth increasing as elevation drops into deeper and more persistent water levels. ANOVA confirms the relationship, with significant F values of 0.0000 for both months. However, regressions for May and August 1992 reflect a growing loss of relationship between basal circumference and elevation, with an R^2 value of 0.48 in May and 0.18 in August. ANOVA significant F value increased from 0.001 in May to 0.12 in August. The increasing lack of dependence of basal circumference on elevation may be due to the restriction of lateral growth by competitors as the growing season progressed, among other factors.

Height was more closely dependent on elevation than basal circumference. Regression analysis for each sampling event produced high

R^2 values for height, ranging from 0.70 to 0.85. ANOVA reported significant F values of 0.0000 for all sampling events. As with basal circumference, height also increases with greater water depth.

Only the August 1991, October 1991, and August 1992 inflorescence counts were used for statistical analysis. *Juncus ensifolius* produced no inflorescences in May 1992. From the 1991 counts, August regression found that inflorescence number varied significantly according to elevation (R^2=0.66). ANOVA supported the relationship with a significant F value of 0.0000. October regression and ANOVA analyses indicate a weakening in the relationship between elevation and inflorescences that is to be expected as plants begin to senesce in the fall (R^2=0.49, significant F= 0.0006). The August 1992 regression for inflorescences, however, showed a weaker relationship (R^2= 0.37, significant F= 0.02). Inflorescence number, like basal circumference and height, also rose with lower elevations.

Figure 7-1 shows the correlation between growth parameters and relative elevation for *Juncus ensifolius*. Table 7-1 shows the regression and ANOVA significance values.

Scirpus cyperinus

Scirpus cyperinus was monitored along an elevation gradient running from 1.81 to 1.30 feet. Basal circumference, height, and inflorescence numbers for *Scirpus cyperinus* were taken during every sampling event except December 1991. Stem number was reported only in May and August 1992.

Regressions of stem number on elevation for May and August 1992 indicate that the number of stems vary significantly with the change in elevation (R^2=0.63 and 0.69). ANOVA verified the relationship with a significant F value of 0.0000 for both month's data sets. Individual stem number grew with more persistently wet conditions at lower elevations.

Regression analysis overall confirmed that basal circumference depended on elevation. Regressions for basal circumference measurements from August 1991, May 1992, and August 1992 had similar R^2 values (0.59, 0.62, and 0.69, respectively), with ANOVA significant F values affirming the relationship (0.0001, 0.0001, and 0.0000, respectively). The October 1991 regression was weaker but still correlated with an R^2 value of 0.40 at a significant F value of 0.0029. This may reflect the loss of biomass that

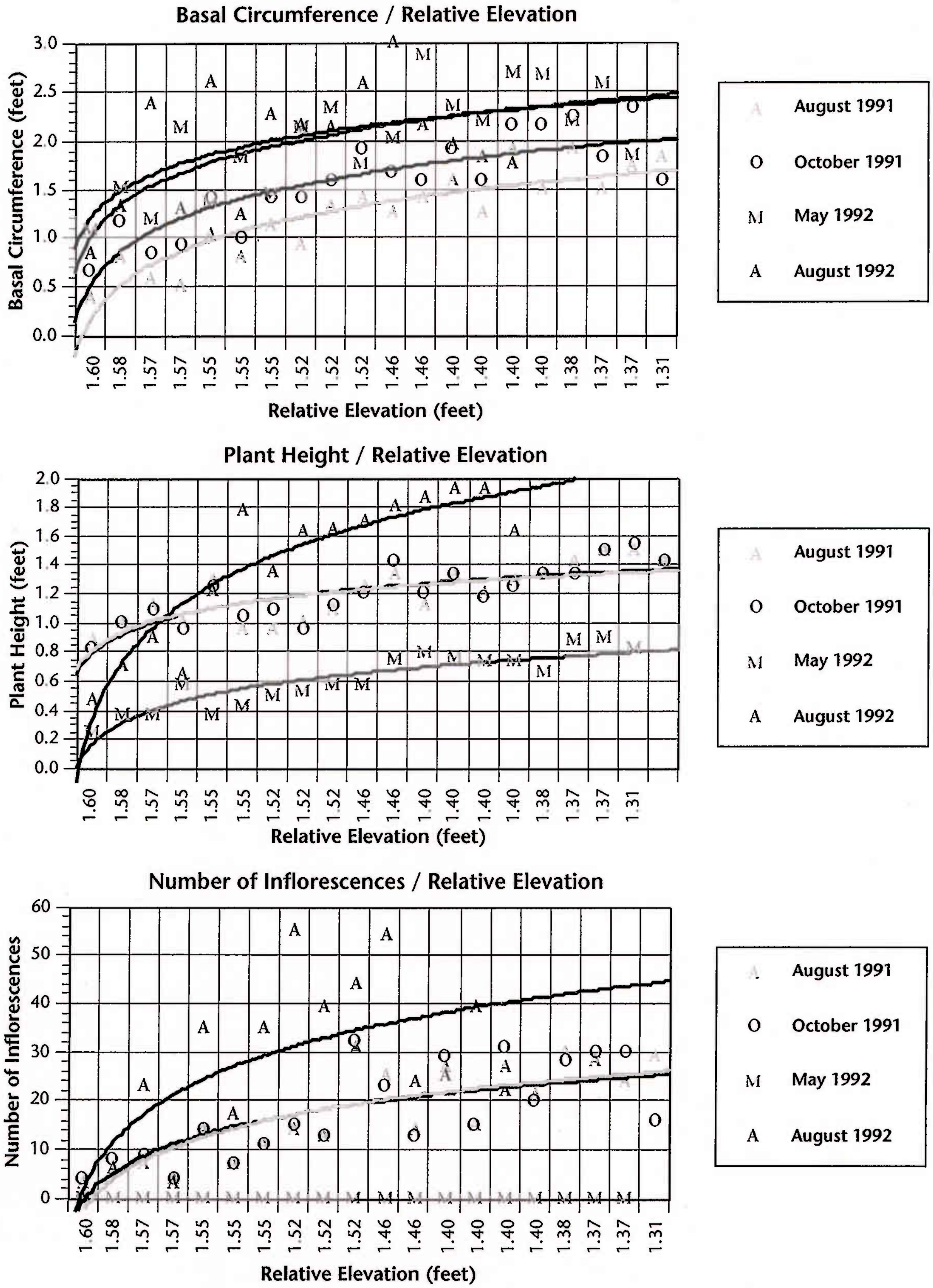


Figure 7-1. Correlation Between Growth Parameters and Relative Elevation for *Juncus ensifolius* with Best Fit Log Transformed Lines

TABLE 7-1. Regression and ANOVA Significance Values for *Juncus ensifolius*

Date	R^2	ANOVA Significant F	Significant Relationship?
Basal Circumference			
August 1991	0.7725	0.0000	yes
October 1991	0.6121	0.0000	yes
May 1991	0.4817	0.0010	yes
August 1992	0.1765	0.1190	no
Height			
August 1991	0.7246	0.0000	yes
October 1991	0.7026	0.0000	yes
December 1991	0.7848	0.0000	yes
May 1992	0.8500	0.0000	yes
August 1992	0.8305	0.0000	yes
Number of Inflorescences			
August 1991	0.6609	0.0000	yes
October 1991	0.4901	0.0006	yes
May 1992	no inflorescences	no inflorescences	no inflorescences
August 1992	0.3718	0.0158	yes

occurs during senescence in the fall. As expected, the trend was toward greater basal circumference with decreasing elevation.

Height consistently depended on elevation for all sampling events. Regression R^2 values supported the relationship, with very similar values during the study, ranging from 0.59 to 0.64. ANOVA significant F values confirmed the strength of the relationship. Plant height tended to increase down the elevation gradient.

Regression analysis of the relationship between number of inflorescences and plant elevation was fairly strong at 0.37 and 0.44, respectively. ANOVA significant F values support a significant relationship. October 1991 regression and ANOVA tests revealed no significant relationship between inflorescence number and elevation, as might be expected toward the end of the growing season. *Scirpus cyperinus* had not produced any inflorescences yet in May 1992.

Figure 7-2 shows the correlation between growth parameters and relative elevation for *Scirpus cyperinus*. Table 7-2 shows the regression and ANOVA significance values.

Scirpus acutus

Vigor measurements were gathered along an elevation gradient from 1.73 to 1.13 feet. Height, inflorescence, and stem number were measured at all sampling events except December 1991. Because *Scirpus acutus* lacks a distinctive clustering of stems, basal circumference was not monitored.

Regression analysis of the initial measurement of height in August 1991 revealed an indeterminate relationship with elevation, with an R^2 value of 0.40. ANOVA significant F value affirmed that this level of correlation, despite being low, is significant (0.0028). The dependency of height on elevation was stronger in October 1991, May 1992, and August 1992, with regression R^2 values of 0.68, 0.78, and 0.72, respectively. All ANOVA significant F values were 0.0000, supporting the significance of the relationship. *Scirpus acutus* heights increased with lower elevation. This was the tallest study species, reaching heights of up to 7.2 feet.

The number of stems per plant tended to increase down the elevation gradient. Regression analysis confirmed this trend with R^2 values of 0.61, 0.73, and 0.68 for August 1991, October 1991, and May 1992, respectively. ANOVA significant F values showed the dependency of stem number on elevation to be a valid relationship (0.0000). The stem number regression for August 1992 verified only a moderate dependency on elevation, with an R^2 value of only 0.41. The ANOVA significant F value of 0.0054 reflected this. This weakening of relationship between stem number and elevation at the end of the study may result from intraspecies and interspecies competition.

Inflorescences also became more numerous at lower elevations. Regressions for all sample events supported the validity of this trend, with the notable exception of May 1992, where the Durbin-Watson test for serial correlation of the error terms was positive. R^2 values for August 1991, October 1991, and August 1992 were 0.71, 0.64, and 0.57, respectively. A slightly lower August 1992 R^2 value and ANOVA significant F value of 0.0004 may also reflect the effects of competition. Significant F values for August and October 1991 were both 0.0000.

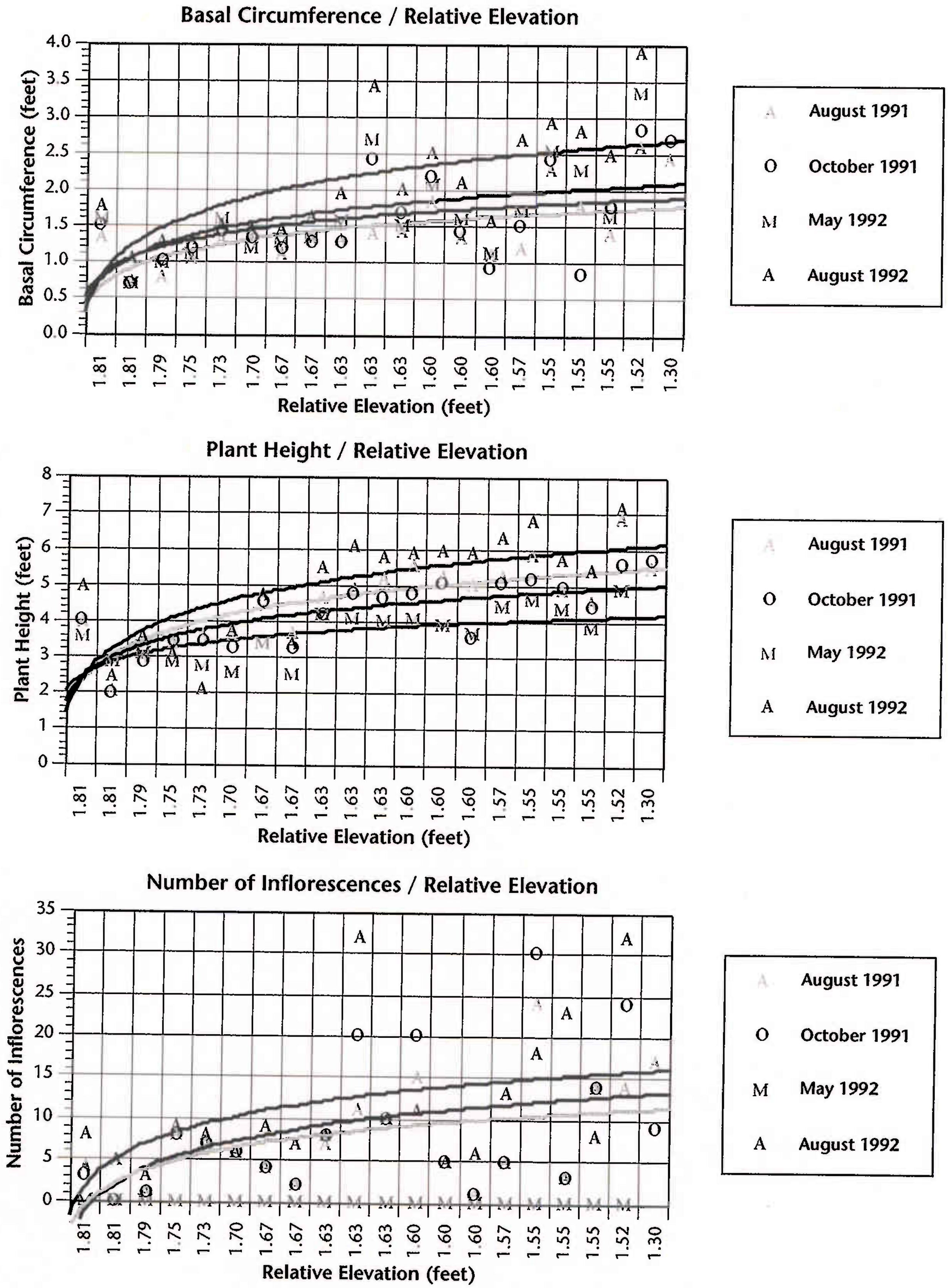


Figure 7-2. Correlation Between Growth Parameters and Relative Elevation for *Scirpus cyperinus* with Best Fit Log Transformed Lines

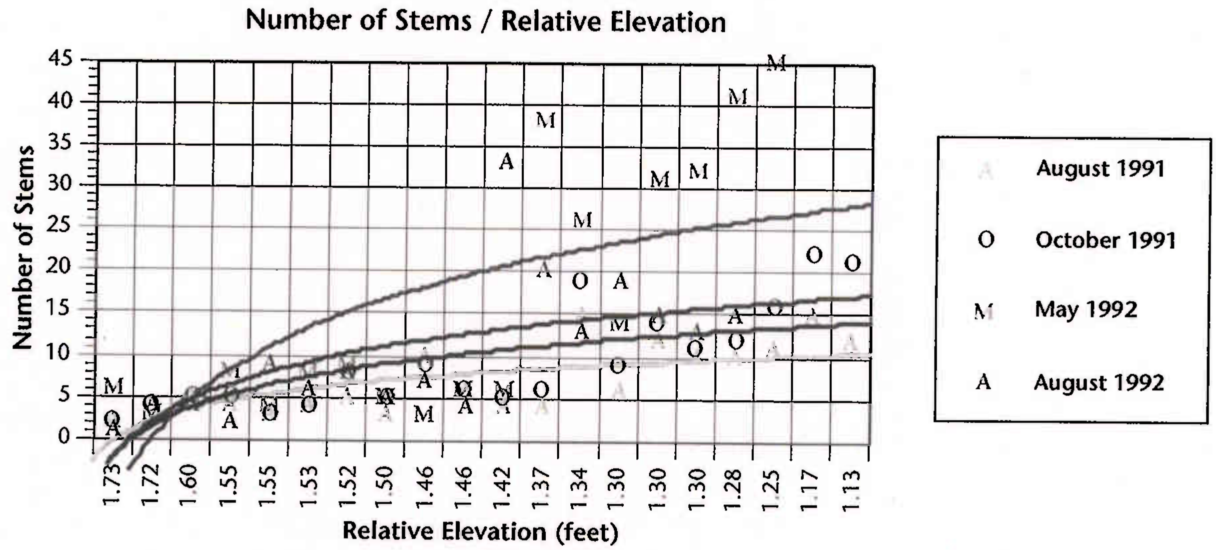
TABLE 7-2. Regression and ANOVA Significance Values for *Scirpus cyperinus*			
Date	R^2	ANOVA Significant F	Significant Relationship?
Number of Stems			
May 1992	0.6360	0.0000	yes
August 1992	0.6894	0.0000	yes
Basal Circumference			
August 1991	0.5867	0.0001	yes
October 1991	0.3973	0.0029	yes
May 1992	0.6150	0.0001	yes
August 1992	0.6942	0.0000	yes
Height			
August 1991	0.5868	0.0001	yes
October 1991	0.6415	0.0000	yes
May 1992	0.6003	0.0001	yes
August 1992	0.6066	0.0001	yes
Number of Inflorescences			
August 1991	0.3693	0.0045	yes
October 1991	0.1766	0.0651	no
May 1992	no inflorescences	no inflorescences	no inflorescences
August 1992	0.4369	0.0021	yes

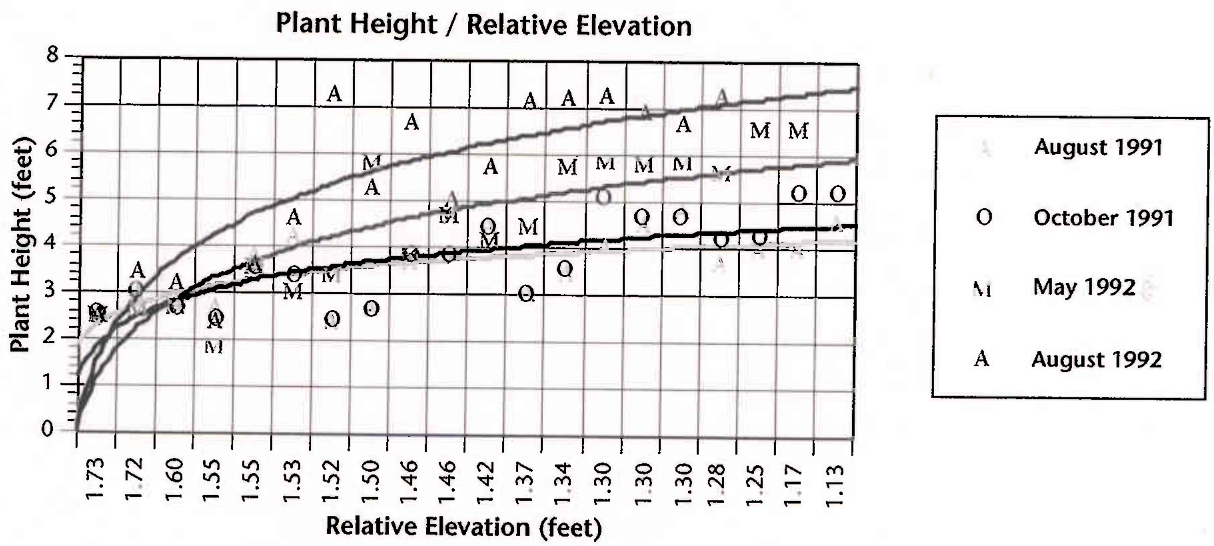
Figure 7-3 shows the correlation between growth parameters and relative elevation for *Scirpus acutus*. Table 7-3 shows the regression and ANOVA significance values.

Juncus effusus

The growth parameters for *Juncus effusus* were taken within the range of elevation running from 1.73 to 1.09 feet. Height and basal circumference measurements were gathered on all sampling events. December 1991 basal measurements were taken as diameters. Inflorescence and stem number were also counted for all sampling events except for December 1991.

No significant relationship was found between the given range of elevation and basal circumference. Regression analysis R^2 values ranged from 0.17 to 0.003, with ANOVA significant F values reaffirming a lack of





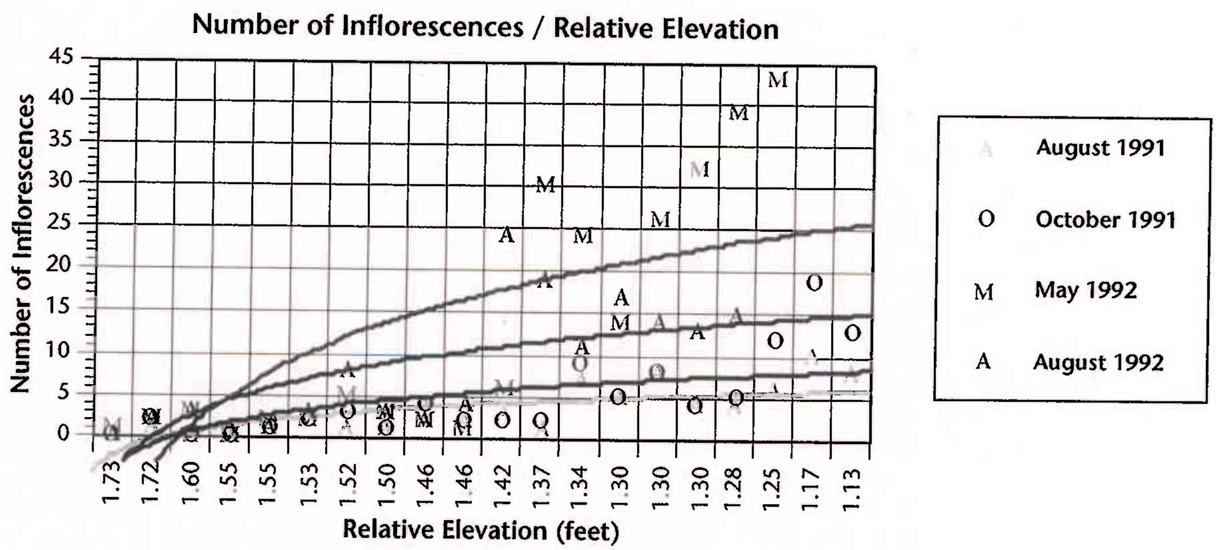


Figure 7-3. Correlation Between Growth Parameters and Relative Elevation for *Scirpus acutus* with Best Fit Log Transformed Lines

TABLE 7-3. Regression and ANOVA Significance Values for *Scirpus acutus*			
Date	**R^2**	**ANOVA Significant F**	**Significant Relationship?**
		Height	
August 1991	0.3985	0.0028	yes
October 1991	0.6850	0.0000	yes
May 1992	0.7763	0.0000	yes
August 1992	0.7170	0.0000	yes
		Number of Stems	
August 1991	0.6130	0.0000	yes
October 1991	0.7277	0.0000	yes
May 1992	0.6767	0.0000	yes
August 1992	0.4136	0.0054	yes
		Number of Inflorescences	
August 1991	0.7145	0.0000	yes
October 1991	0.6420	0.0000	yes
May 1992	0.7317	0.0000	yes
August 1992	0.5718	0.0004	yes

correlation. A graph of basal circumference versus elevation displayed no discernible trend in circumference along the elevation gradient.

Regression R^2 values for August and October 1991 reflected the lack of correlation between variation in stem number and change in elevation. However, the R^2 values steadily increased with each sampling event, from 0.0009 in August 1991 to August 1992, where the correlation proved significant with an R^2 value of 0.53. ANOVA significant F values also followed this trend, starting in August 1991 with 0.9023 and dropping to 0.0004 in August 1992. The strengthening of this relationship over the study may reflect the maturing of the plants over time.

Variation in inflorescence number showed no significant relationship with change in elevation during the study. But, as with the stems, regression R^2 values increased during the study, from 0.002 in August 1991 to 0.474 in August 1992, with a concurrent fall in ANOVA significant F values from 0.85 to 0.02.

Height was the only vigor measurement that proved to be positively correlated with elevation, gradually increasing toward lower elevations. Regression analysis for October 1991, December 1991, May 1992 and August 1992 supported this relationship, yielding R^2 values of 0.75, 0.62, 0.71, and 0.52 respectively, with ANOVA significant F values of 0.0000, 0.0000, 0.0000, and 0.0005. Regression analysis of August 1991 height on elevation gave an indeterminate R^2 value of 0.42 and an ANOVA significant F value of 0.002.

Figure 7-4 shows the correlation between growth parameters and relative elevation for *Juncus effusus*. Table 7-4 shows the regression and ANOVA significance values.

Scirpus microcarpus

Basal circumference, height, inflorescence and stem number were taken on all sampling events except December 1991, within an area ranging from 1.81 to 1.17 feet in elevation. Regression and ANOVA analysis of stem number and inflorescence number did not reveal any significant correlation between variation in these growth parameters and change in elevation.

The regression and ANOVA analysis of August and October 1991 height on elevation showed strong relationship, with R^2 values of 0.57 and 0.61 and significant F values of 0.0001 and 0.0000. May and August 1992 regression and ANOVA analysis, however, found the relationship between height variation and change in elevation to be insignificant.

Initially, the amount of variability in basal circumference attributable to change in elevation was appreciable, with an August 1991 R^2 value of 0.41 and an ANOVA significant F value of 0.003. However, during the study, the significance of the relationship weakened, ending with R^2 and significant F values in August 1992 that reflected an insignificant relationship. This trend in both height and basal circumference may have resulted from increased competition between plants as they fill in available space.

Figure 7-5 shows the correlation between growth parameters and relative elevation for *Scirpus microcarpus*. Table 7-5 shows the regression and ANOVA significance values.

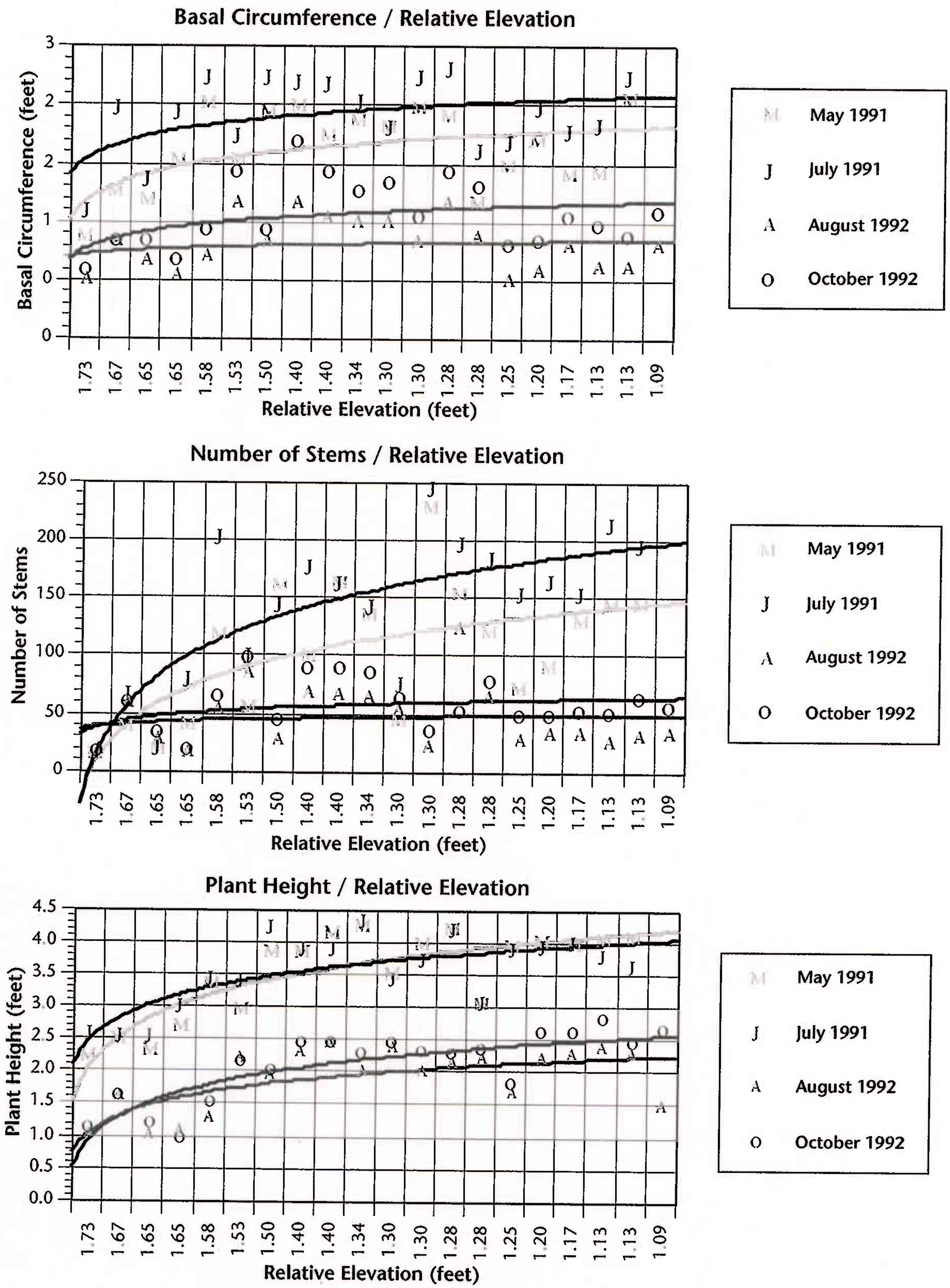


Figure 7-4. Correlation Between Growth Parameters and Relative Elevation for *Juncus effusus* with Best Fit Log Transformed Lines

TABLE 7-4. Regression and ANOVA Significance Values for *Juncus effusus*			
Date	**R^2**	**ANOVA Significant F**	**Significant Relationship?**
Basal Circumference			
August 1991	0.0029	0.8211	no
October 1991	0.0800	0.2269	no
May 1992	0.1706	0.0788	no
August 1992	0.1324	0.1256	no
Number of Inflorescences			
August 1991	0.0021	0.8480	no
October 1991	0.0003	0.9441	no
May 1992	0.2505	0.0291	yes
August 1992	0.4737	0.0192	yes
Number of Stems			
August 1991	0.0009	0.9023	no
October 1991	0.0052	0.3330	no
May 1992	0.3943	0.0040	yes
August 1992	0.5282	0.0004	yes
Height			
August 1991	0.4188	0.0020	yes
October 1991	0.7527	0.0000	yes
December 1991	0.6270	0.0000	yes
May 1992	0.7180	0.0000	yes
August 1992	0.5249	0.0005	yes

Juncus tenuis

All vigor measurements for *Juncus tenuis* were gathered down an elevation gradient from 1.85 to 1.12 feet. Height and basal circumference measurements were taken for all sampling events except for December 1991. Inflorescences were counted only in May and August of 1992. Stems were too numerous to be counted. Regression and ANOVA analysis of all vigor measurements on the given elevation range did not show any positive correlations. The only exception was a weak but significant relationship between variability in basal diameter and change in elevation in August 1992. The graphs confirm the lack of distinct trends in the measured growth parameters versus the elevation range.

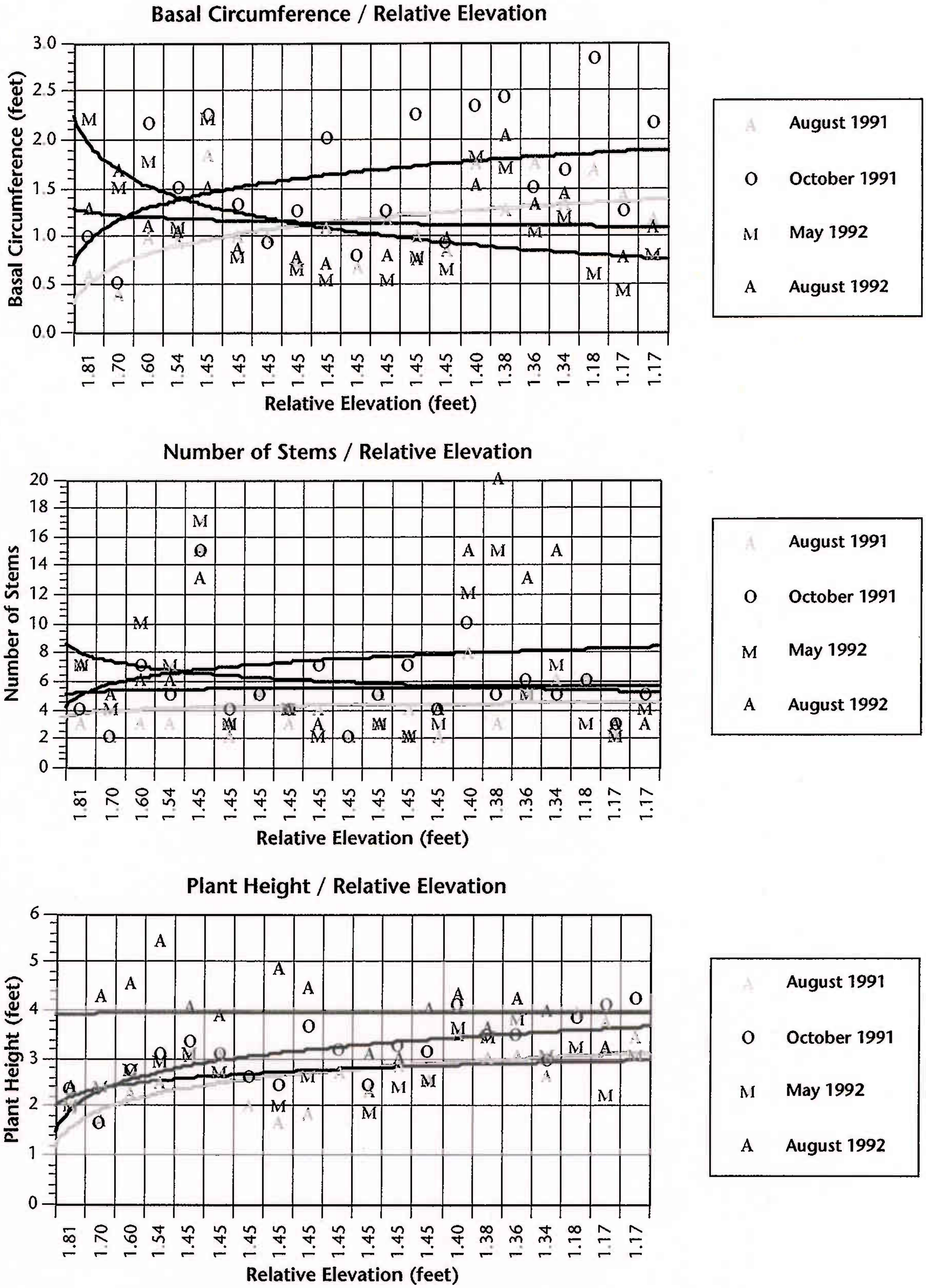


Figure 7-5. Correlation Between Growth Parameters and Relative Elevation for *Scirpus microcarpus* with Best Fit Log Transformed Lines

TABLE 7-5. Regression and ANOVA Significance Values for *Scirpus microcarpus*			
Date	**R^2**	**ANOVA Significant F**	**Significant Relationship?**
	Height		
August 1991	0.5674	0.0001	yes
October 1991	0.6139	0.0000	yes
May 1992	0.1500	0.1124	no
August 1992	0.0018	0.8748	no
	Basal Circumference		
August 1991	0.4126	0.0028	yes
October 1991	0.2132	0.0404	yes
May 1992	0.2997	0.0187	yes
August 1992	0.0241	0.5515	no
	Number of Inflorescences		
August 1991	0.1463	0.0960	no
October 1991	0.1401	0.1040	no
May 1992	0.0070	0.7412	no
August 1992	0.0496	0.3903	no
	Number of Stems		
August 1991	0.0159	0.5957	no
October 1991	0.0063	0.7388	no
May 1992	0.0257	0.5252	no
August 1992	0.0081	0.7306	no

Table 7-6 shows the regression and ANOVA significance values for *Juncus tenuis*. Figure 7-6 shows the correlation between growth parameters and relative elevation.

CLUMP SPECIES

Because *Iris pseudacorus, Typha latifolia, Eleocharis ovata,* and *Sparganium sp.* lacked distinguishable individuals that could be measured for basal circumference, height, inflorescence and stem number along an elevation gradient, they were monitored for the expansion of particular clumps along an elevation gradient. The elevational extremes on the

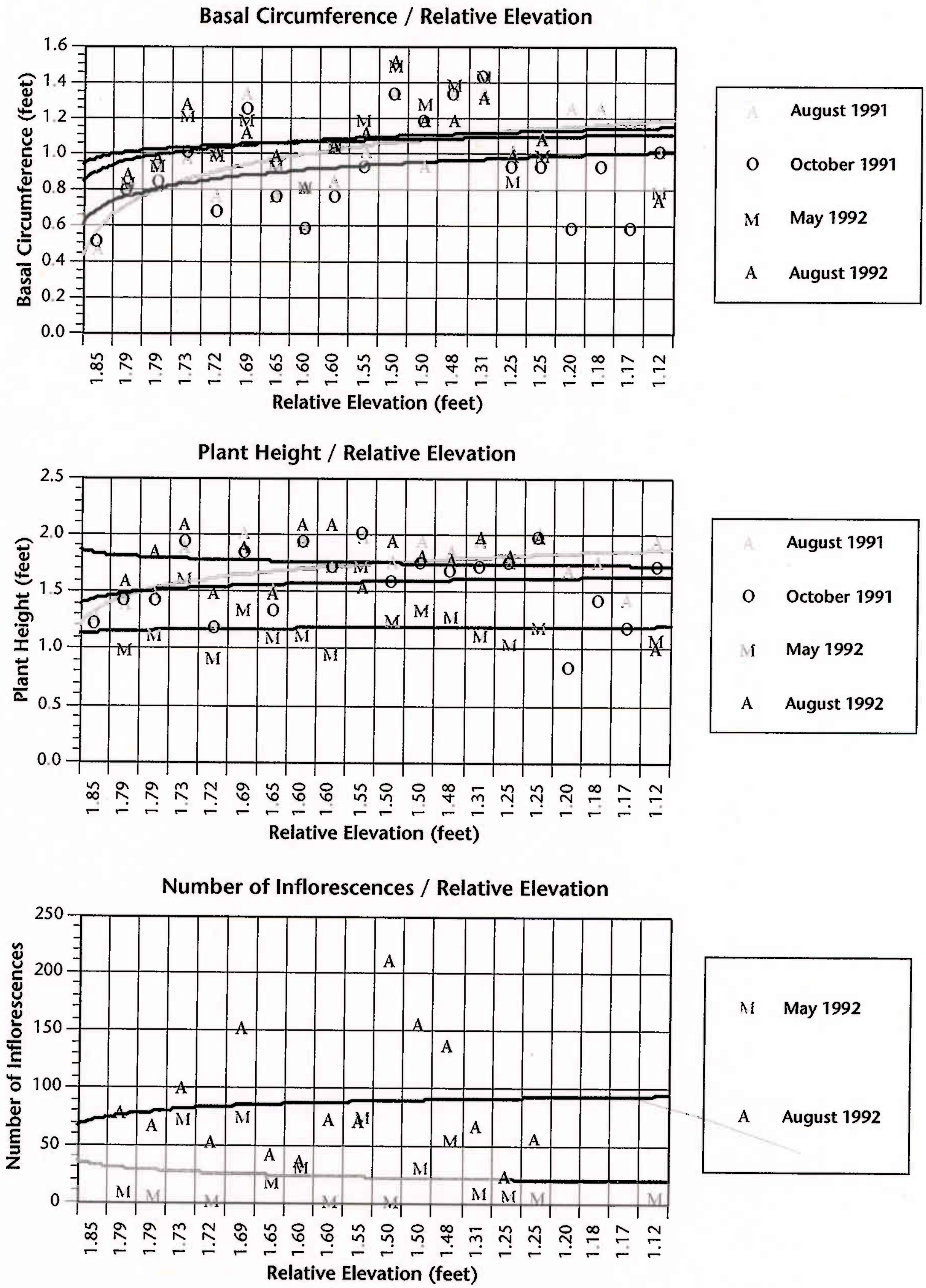


Figure 7-6. Correlation Between Growth Parameters and Relative Elevation for *Juncus tenuis* with Best Fit Log Transformed Lines

TABLE 7-6. Regression and ANOVA Significance Values for *Juncus tenuis*

Date	R^2	ANOVA Significant F	Significant Relationship?
Height			
August 1991	0.1567	0.0841	no
October 1991	0.0008	0.9039	no
May 1992	0.0063	0.7711	no
August 1992	0.0429	0.4417	no
Basal Circumference			
August 1991	0.3270	0.0084	yes
October 1991	0.0212	0.5405	no
May 1992	0.0001	0.9653	no
August 1992	0.1289	0.1571	no
Number of Inflorescences			
August 1991	no inflorescences	no inflorescences	no inflorescences
October 1991	no inflorescences	no inflorescences	no inflorescences
May 1992	0.0786	0.2930	no
August 1992	0.0638	0.3454	no

high/dry and low/wet edge of each clump were determined in October 1991, May 1992, and August 1992.

Typha latifolia covered the broadest range of elevation, spanning from 2.30 to -0.5 feet. *Sparganium sp.* occupied the next widest elevational difference, spreading from 1.87 to -0.5 feet. *Eleocharis ovata* followed next, with a gradient range from 2.14 to 0.5 feet. *Iris pseudacorus* grew in the narrowest elevation range, between 1.97 and 0.8 feet. Figure 7-7 and Table 7-7 show the clump species elevation and water depth ranges.

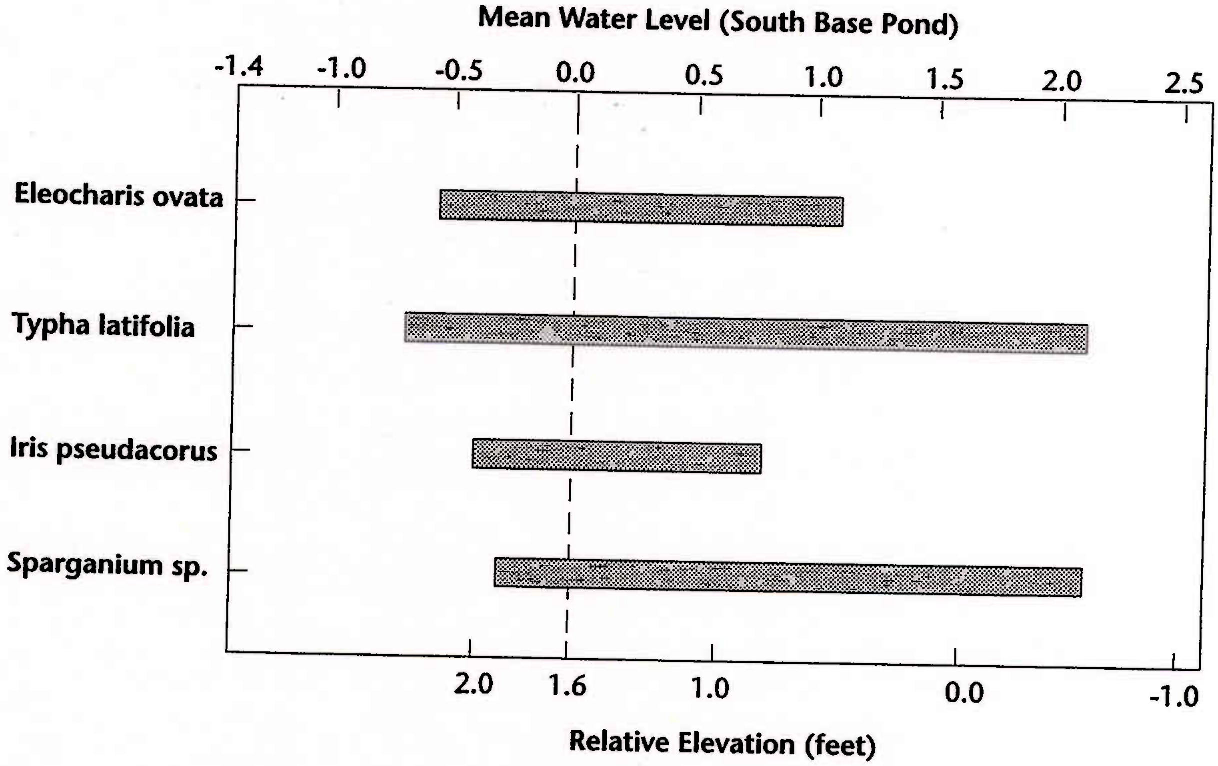


Figure 7-7. Clump Species Elevation and Water Depth Ranges

TABLE 7-7. Clump Species Elevation and Water Depth Ranges

Species	Elevation Range (ft)	Water Depth Range	
		ft	cm
Iris pseudacorus	1.97 to 0.80	-0.38 to 0.79	-11.6 to 24.0
Typha latifolia	2.30 to -0.50	-0.71 to 2.09	-21.6 to 63.7
Eleocharis ovata	2.14 to 0.50	-0.55 to 1.09	-16.8 to 33.2
Sparganium sp.	1.87 to -0.50	-0.28 to 2.09	-8.5 to 63.7